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Long-term satellite, balloon sonde and ground-based observations of SO_2 emissions from Volcán Turrialba, Costa Rica

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Sentinel-5P Mission: 5 Years Anniversary – Taormina, Sicily – 10-14 October 2022

Background and Motivation

- Since the very first Ticosonde CFH and ECC launches in 2005, **notches in the ozone profiles** have been observed frequently
- The growing activity of Turrialba Volcano less than 50 km upwind suggested that these notches were caused by **SO_2 interfering with the O_3 measurement chemistry** within the ECC cathode
- This was confirmed with the first dual-ozonesonde launch at San José in February 2012
- Ticosonde SO_2 measurements of plume height are useful for *in situ* validation
- However, there remain significant challenges for validation of satellite column estimates due to **sampling considerations**, both temporal and spatial, as well as the limitations of the **ozonesonde-interference measurement**
- The higher resolution of TROPOMI SO_2 measurement should be a substantial improvement over the lower-resolution OMI measurements
- On the instrumentation side, the new SO2 sonde isaddressing the limitations of the inferred and dual ozonesonde approaches

Outline

- Ground-based & sonde measurements of SO_2 from Volcán Turrialba, Costa Rica
  - OVSICORI's dual-DOAS flux measurement system on the Turrialba summit dome
  - SO_2 notches/layers in ozonesonde profiles downstream of the volcano
  - Altitude of the SO_2 notches/layers
- Examples of single-pixel match-ups of sonde SO_2 to (*i*) OMI PCA retrieval and *(ii)* Sentinel 5P VCD
- Show OMI PCA total column SO_2 station times series San José, 2004 to present
- Compare mean TRL and max TRL and statistics of relationship to sonde SO_2
- Contrast improved S5P VCD relationship to sonde SO_2 since 2018
- Compare dual sonde vs. SO_2 sonde techniques and advantages of latter
- Summary and conclusions

Data kindly provided by (i) ***Can Li,*** *NASA GSFC/UMD and (ii)* ***Nicolas Theys,*** *BIRA-IASB*

DOAS SO_2 flux: West slope of Turrialba

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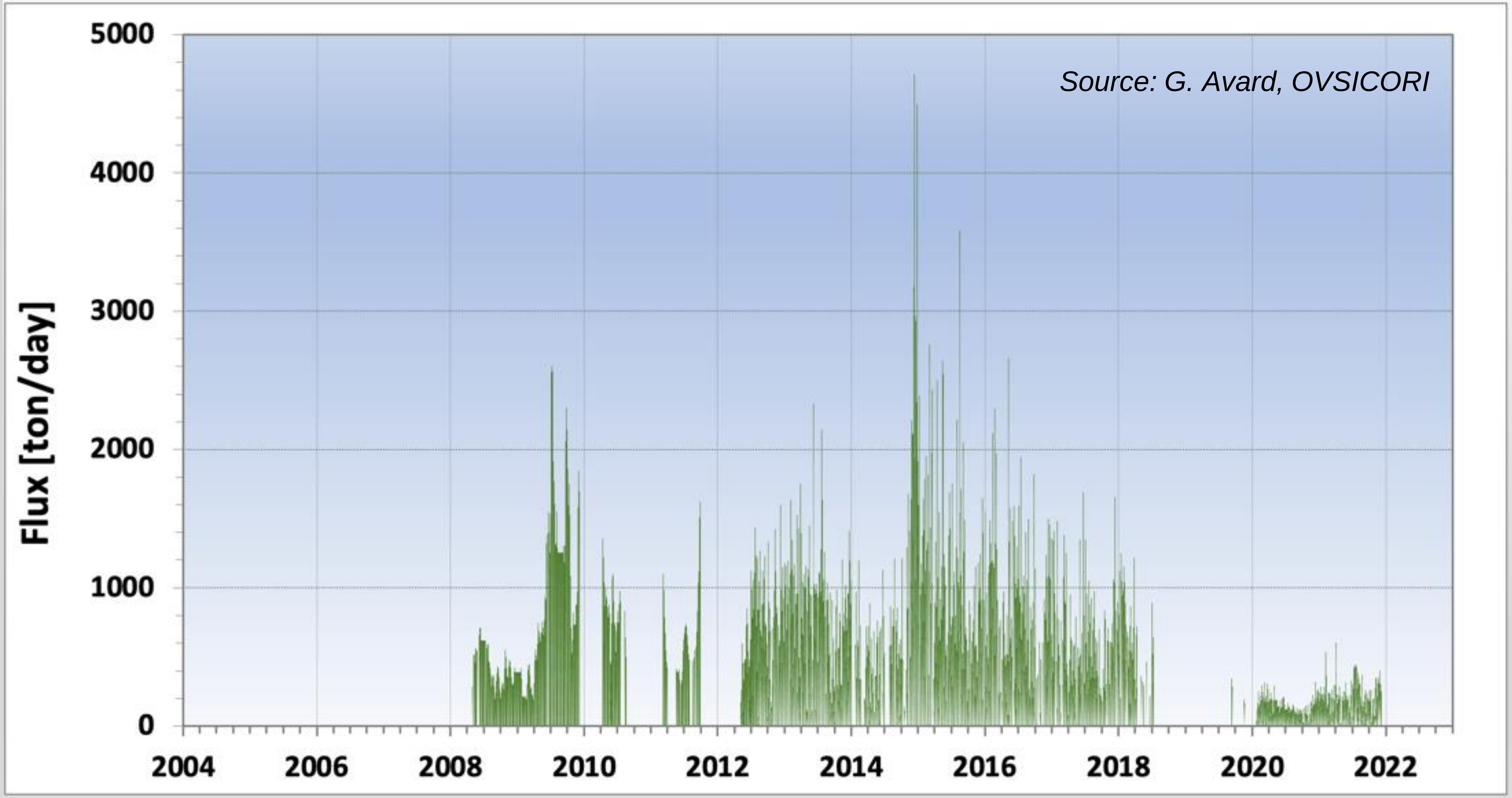

SO_2 notches in ozonesonde profiles

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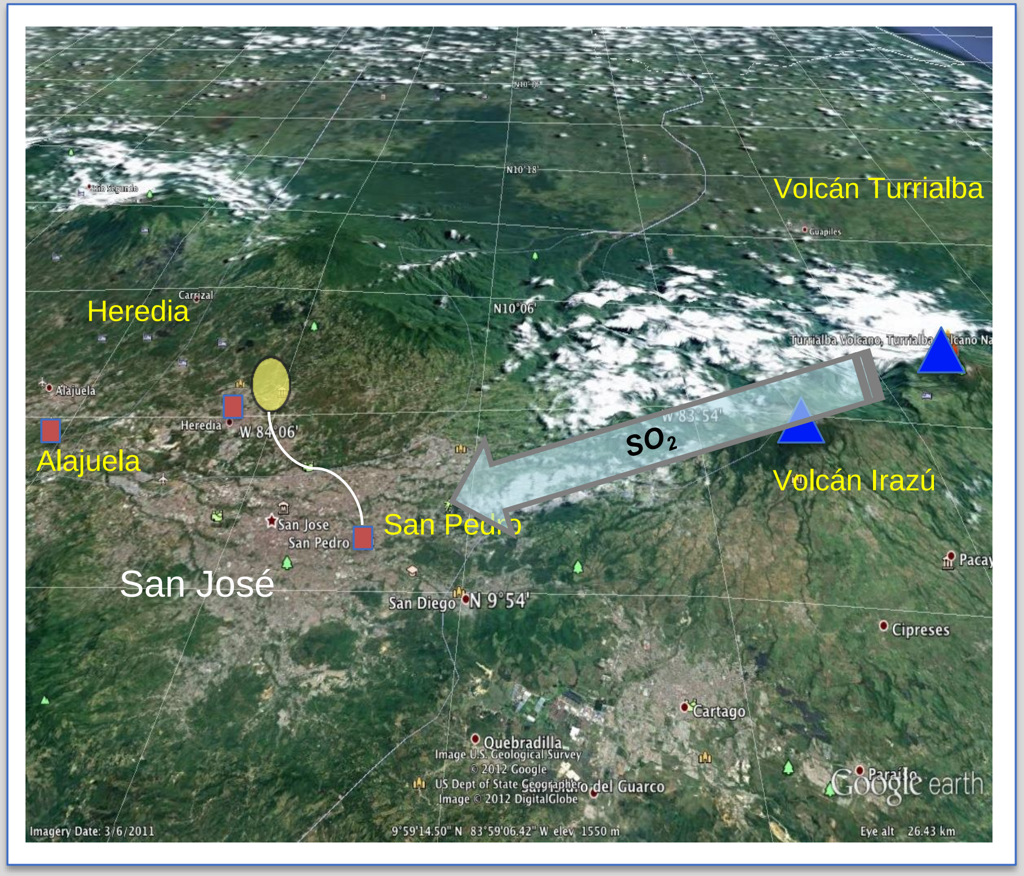

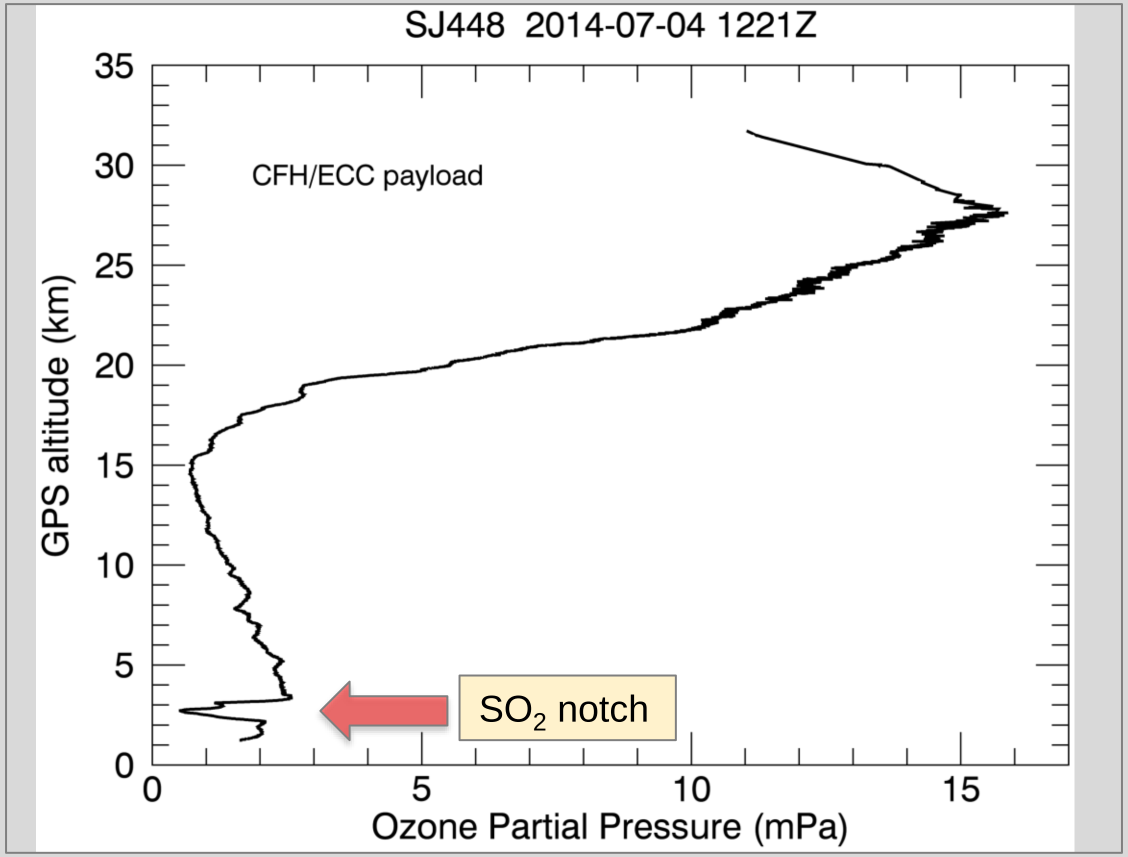

Since 2005, layers of SO_2 have appeared as interference notches in ozone profiles launched from the successive Ticosonde sites at Alajuela, Heredia and San Pedro. All are located downstream of Turrialba and the notches are due to SO_2 emitted from the volcano.

Ozonesonde 'notch' SO_2 @ San José

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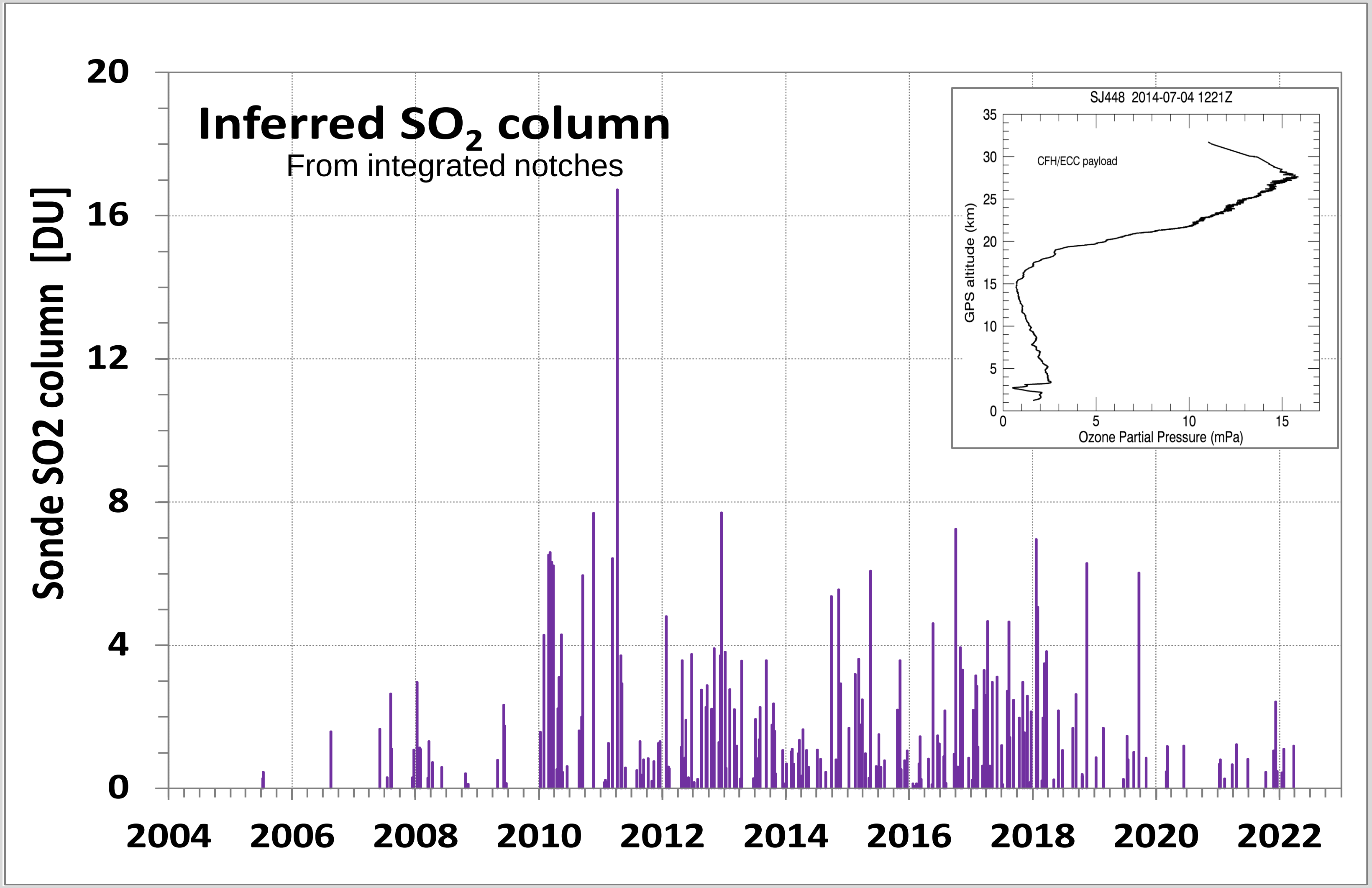

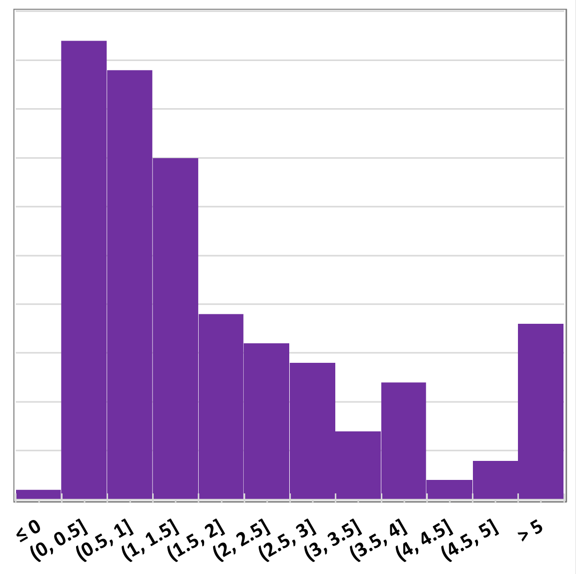

Average = 1.89 DU
Std Dev = 2.00 DU
n = 217

SO_2 notch altitude

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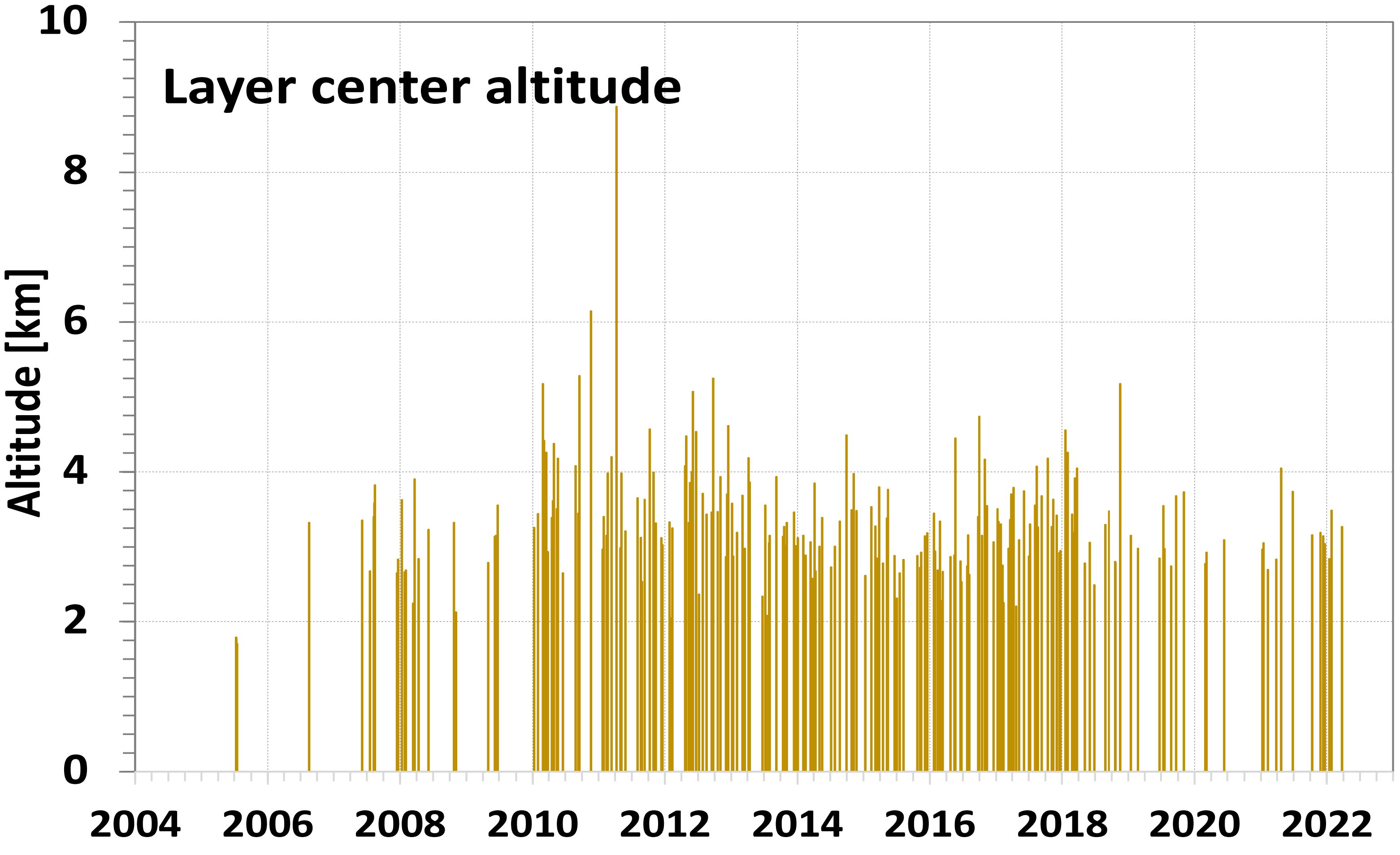

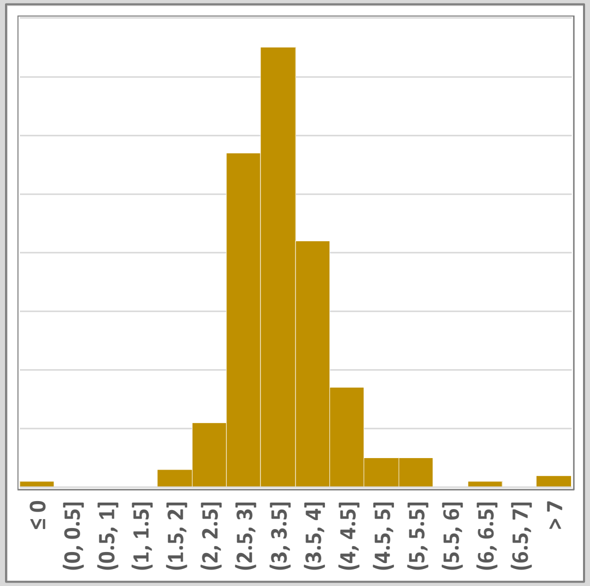

Average = 3.35 km
Std Dev = 0.76 km
n = 217

Sonde SO_2 and OMI PCA TRL

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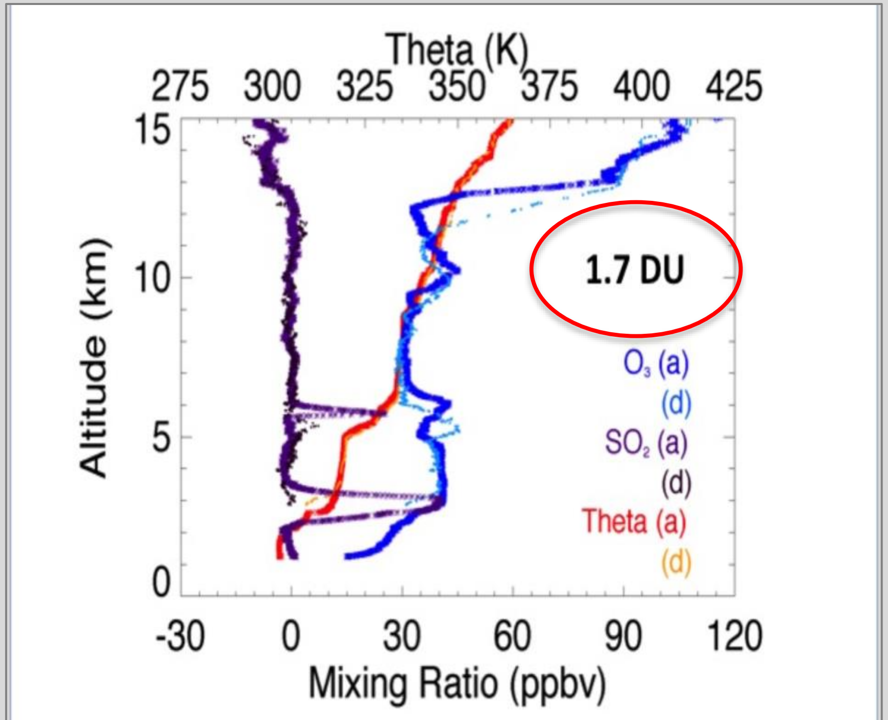
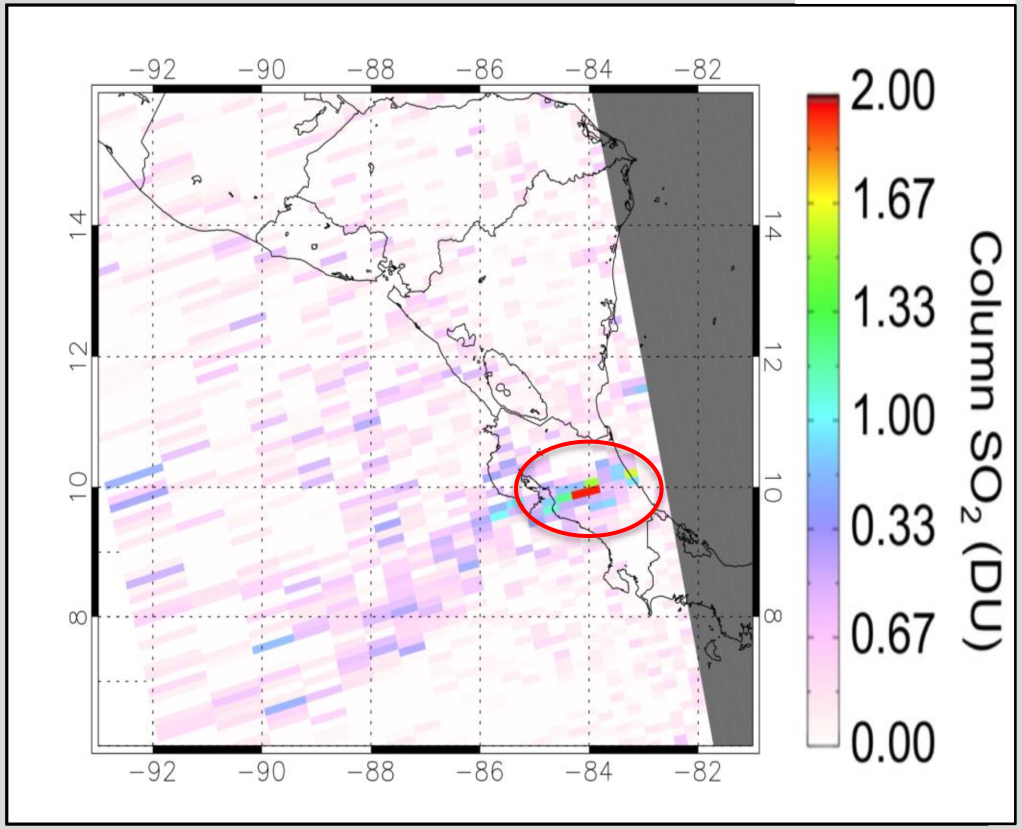
Sonde - 13 March 2015



(Derived SO_2 in two layers)

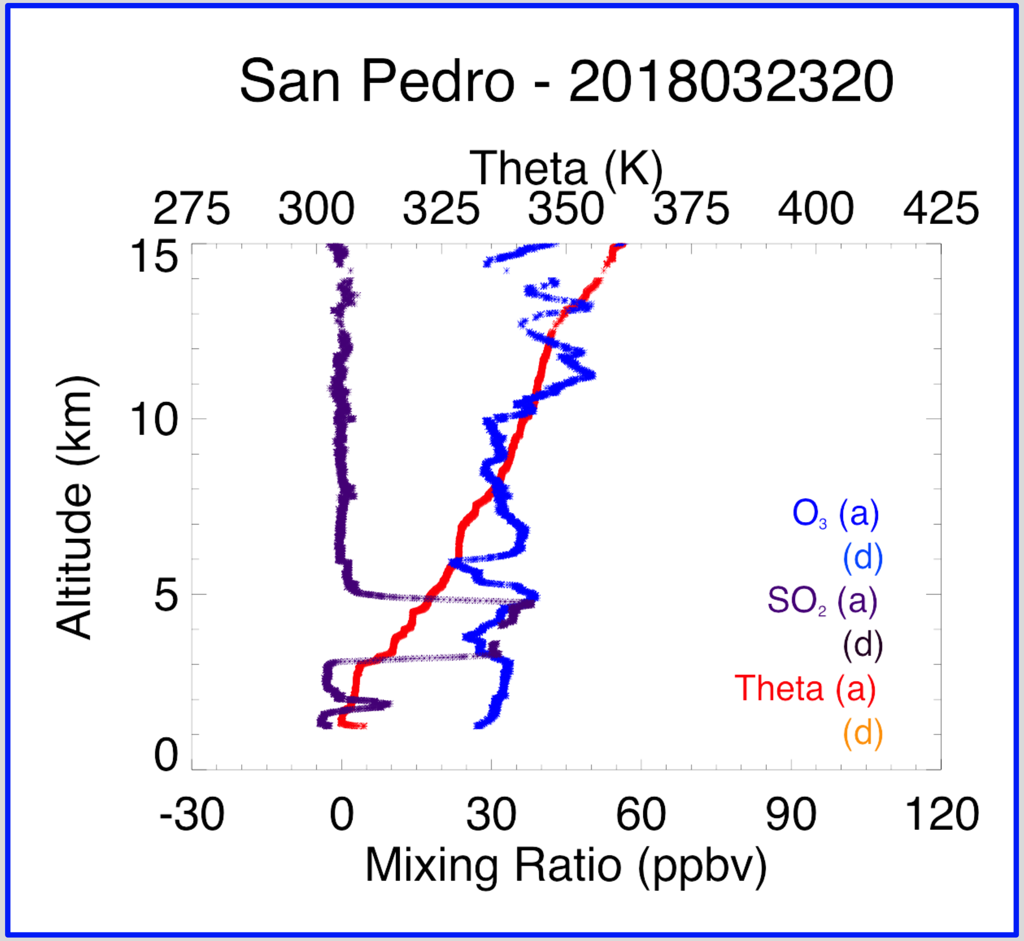
Tropospheric column derived from the dual sonde technique* is 1.7 DU SO_2. Sonde column in excellent agreement with single, co-located OMI PCA pixel.

OMI PCA TRL - 13 March 2015

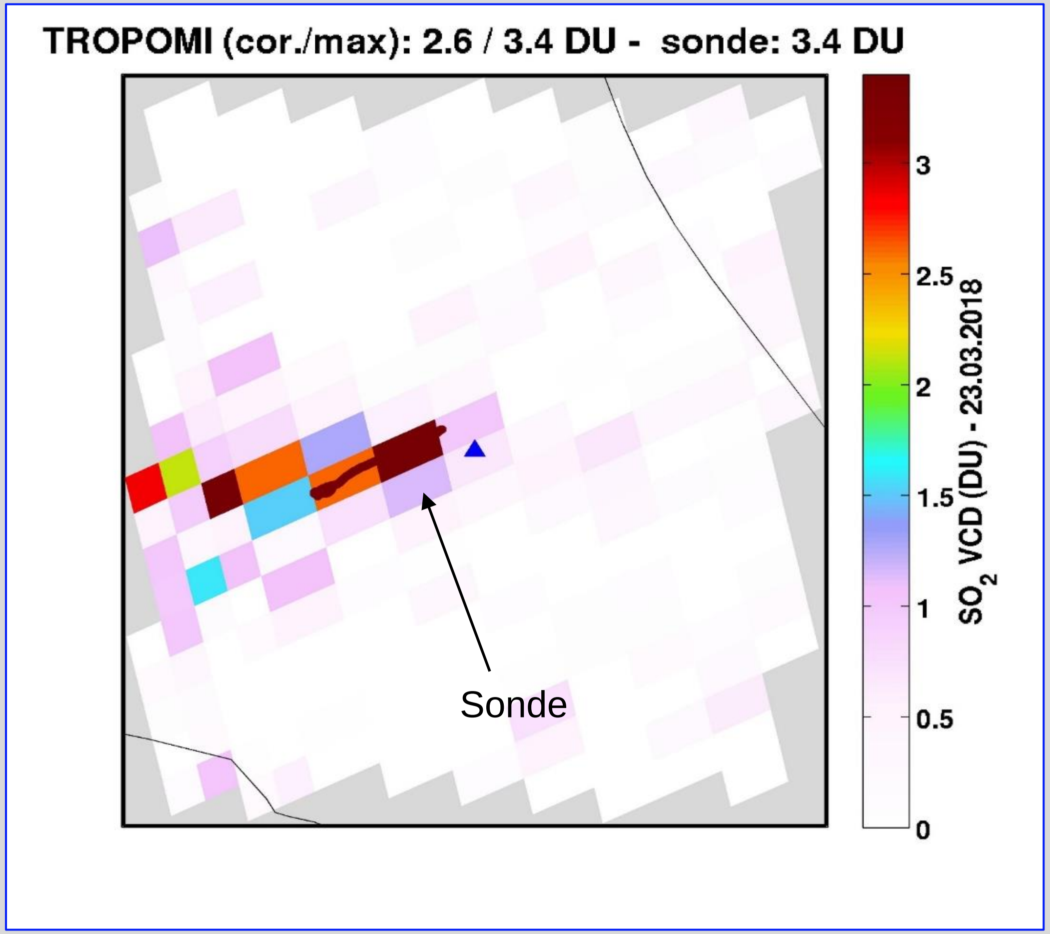


*The dual-sonde technique is based on the same principle as the inferred approach.

Dual sonde SO_2 and TROPOMI VCD



Dual Sonde ⇒ 3.4 DU
(w/ averaging kernel)



3.4 DU over sonde!

OMI PCA TRL (3-km) retrievals at San José

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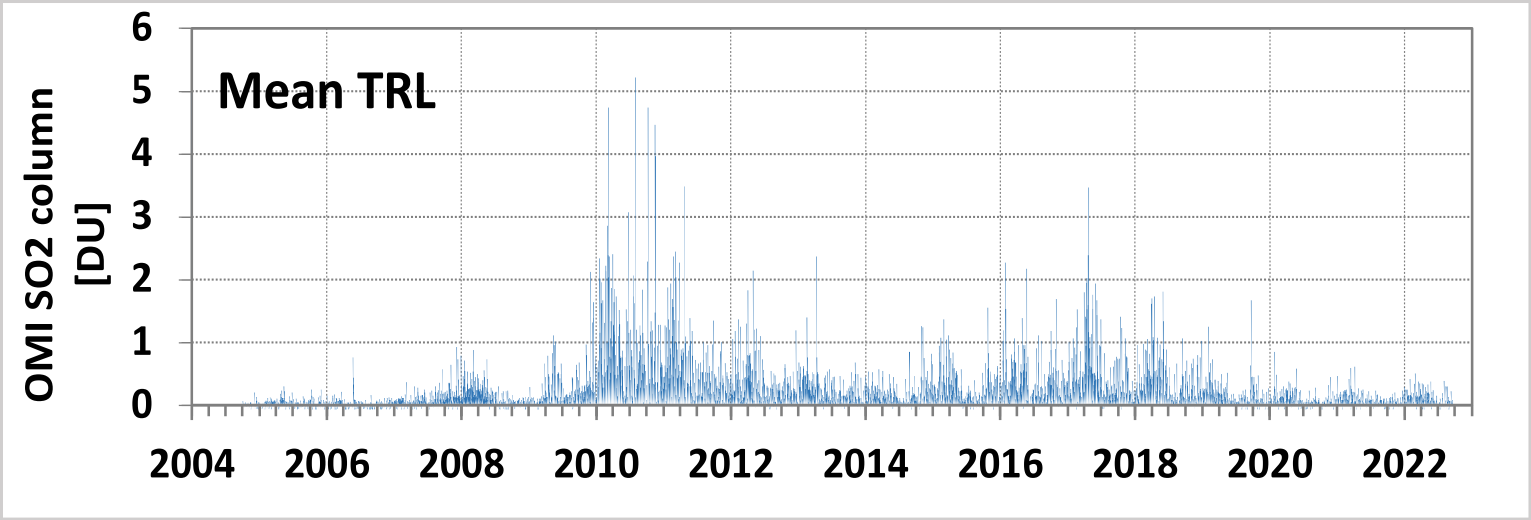
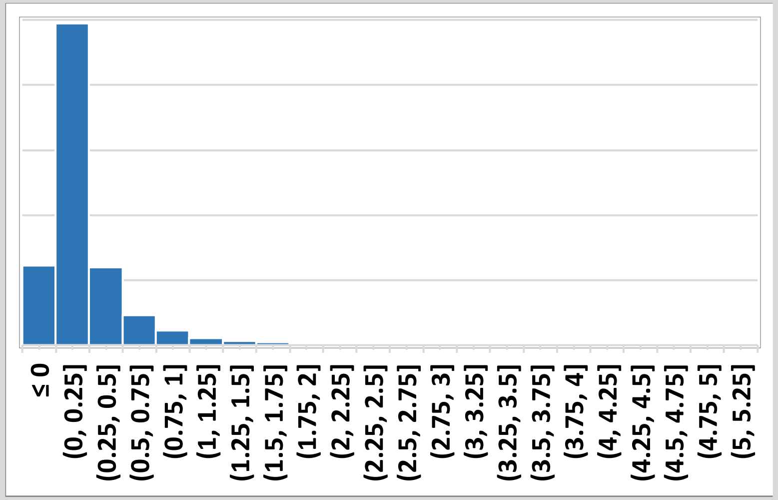
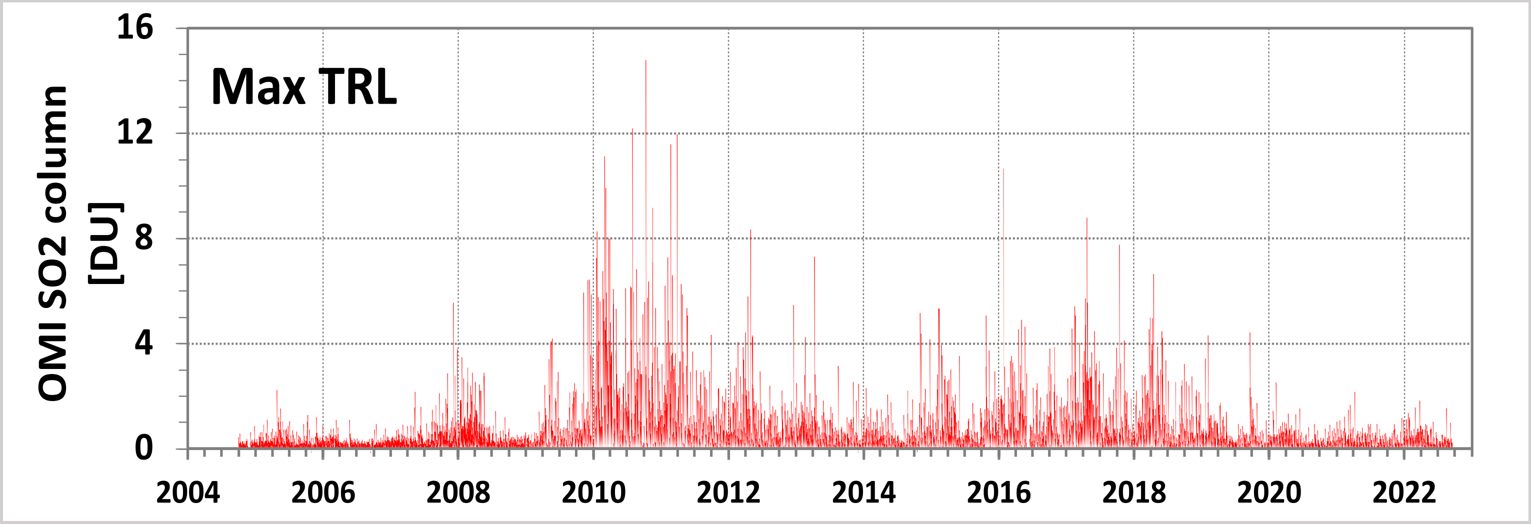
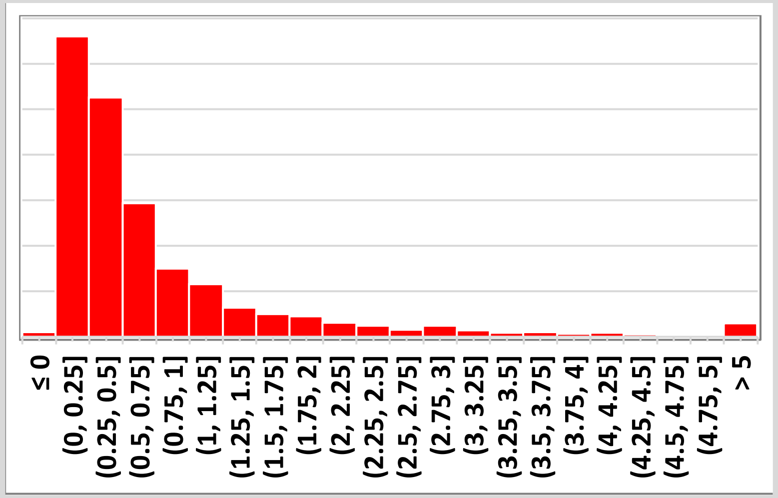


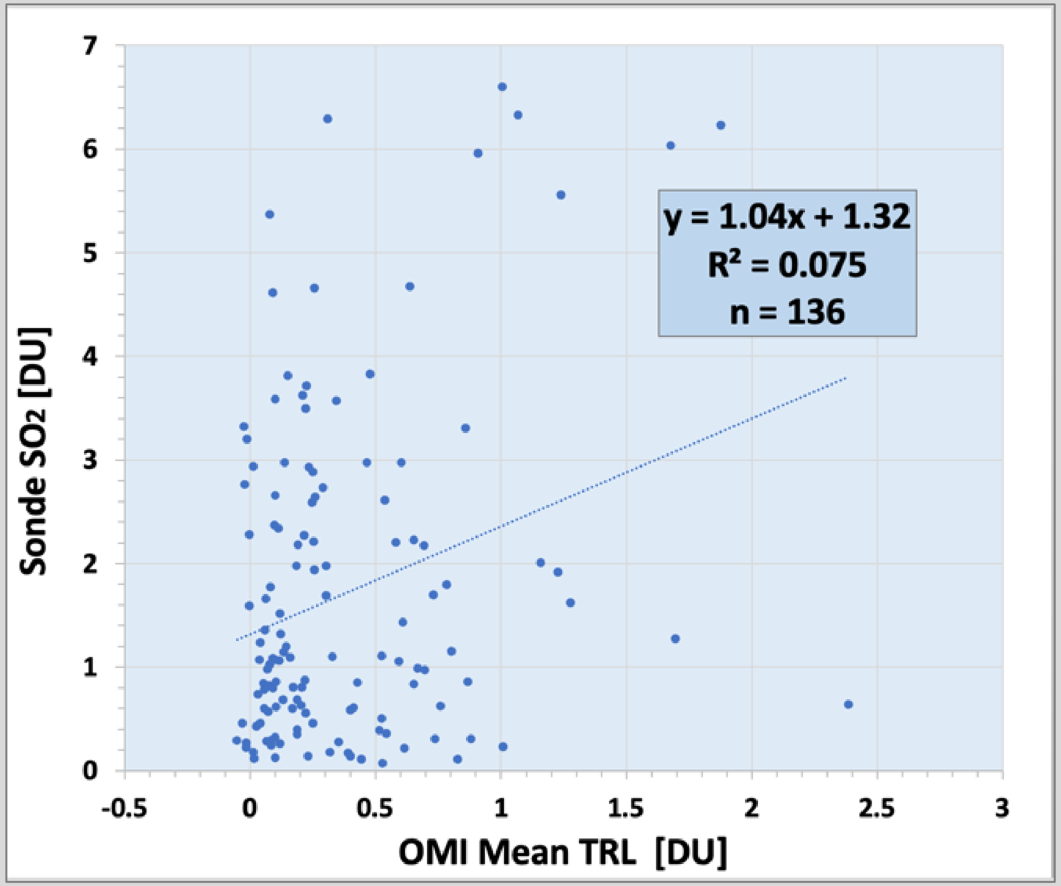


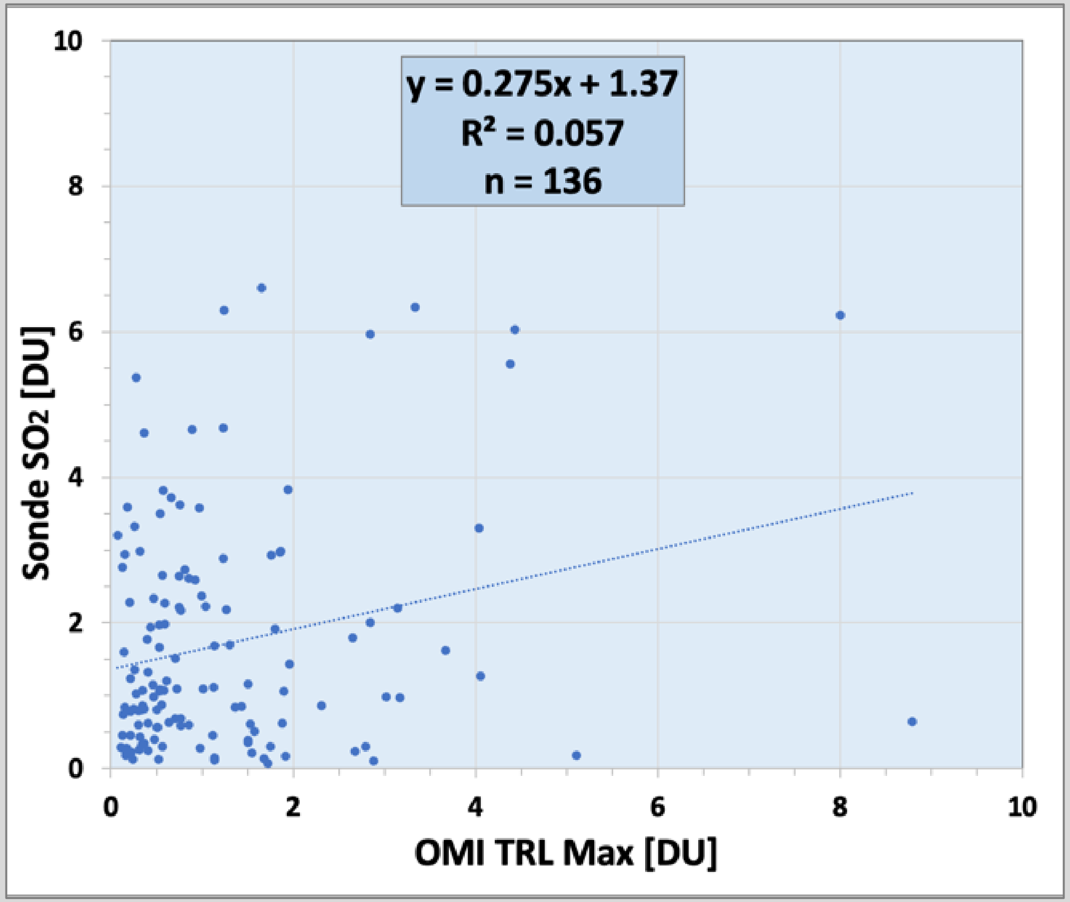




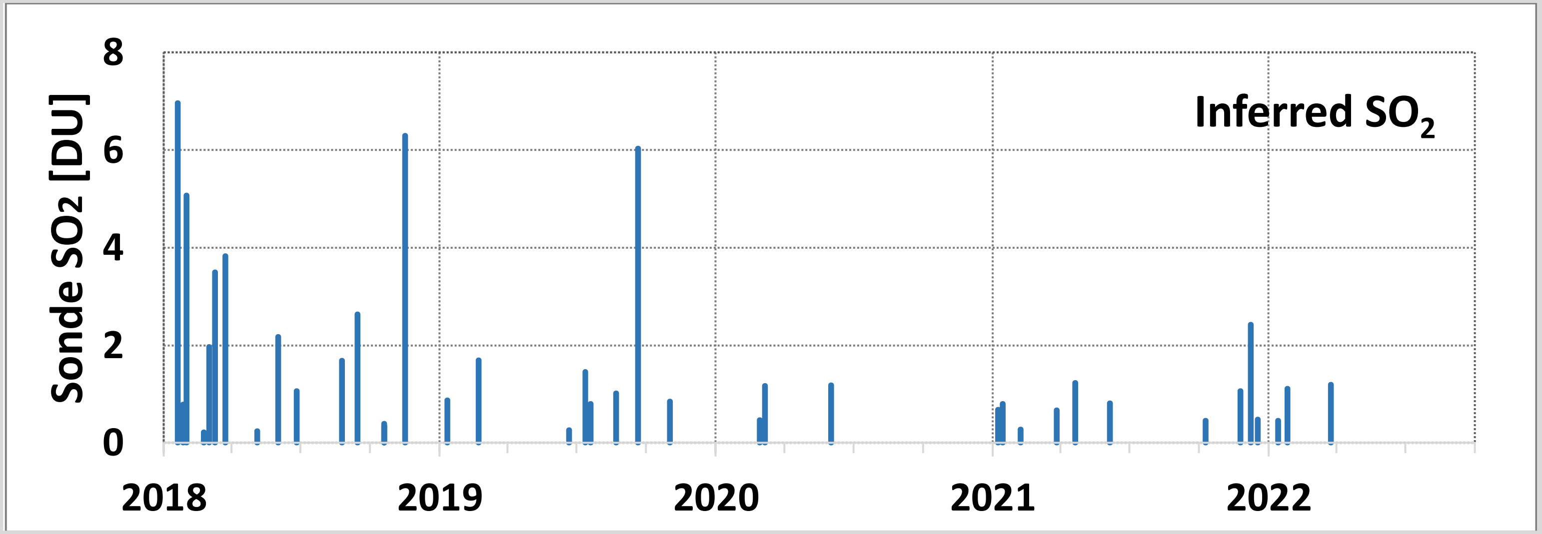
Sonde SO_2 vs Mean and Max OMI TRL

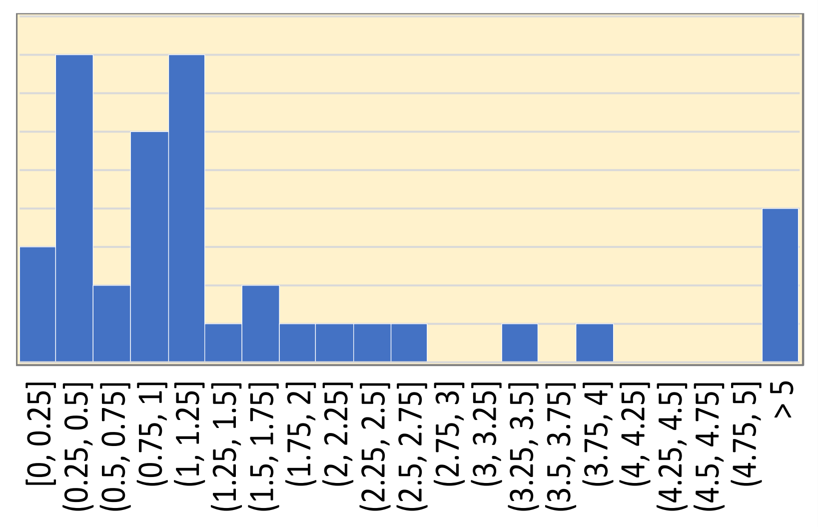
7/8/05 – 3/24/22

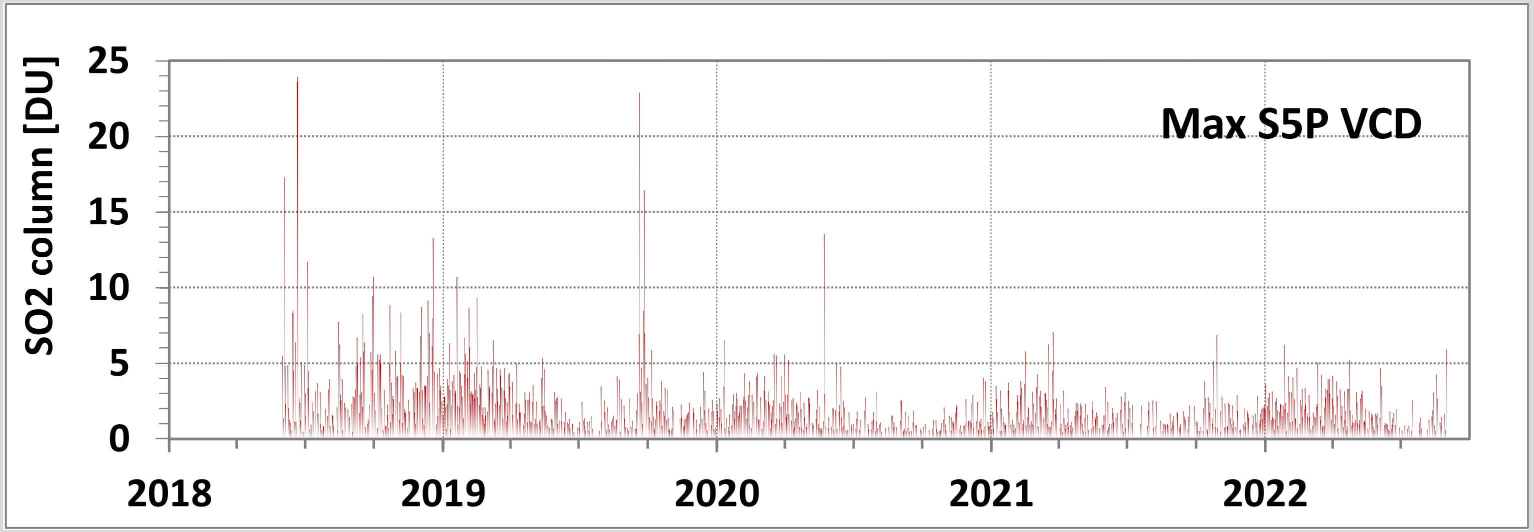


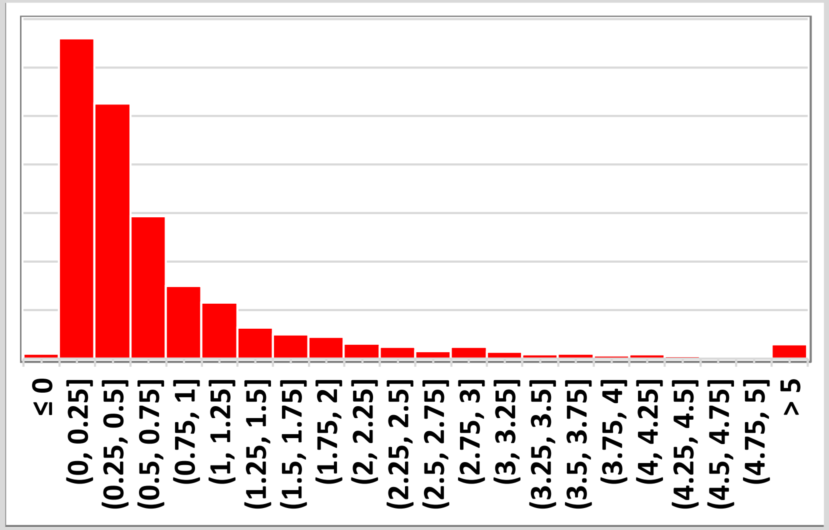


Sonde SO_2 and Max OMI TRL









Sonde SO_2 vs Mean and Max SP5 VCD

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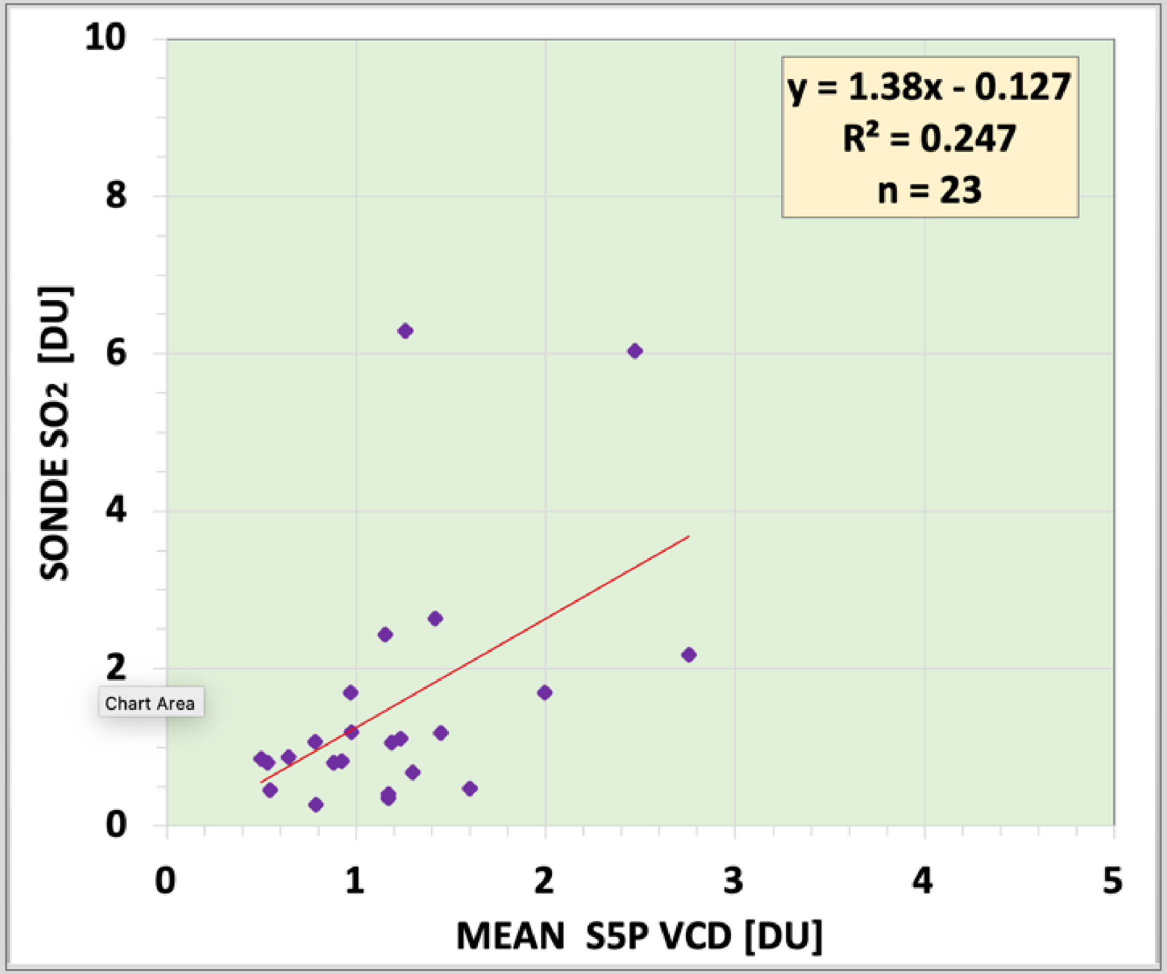
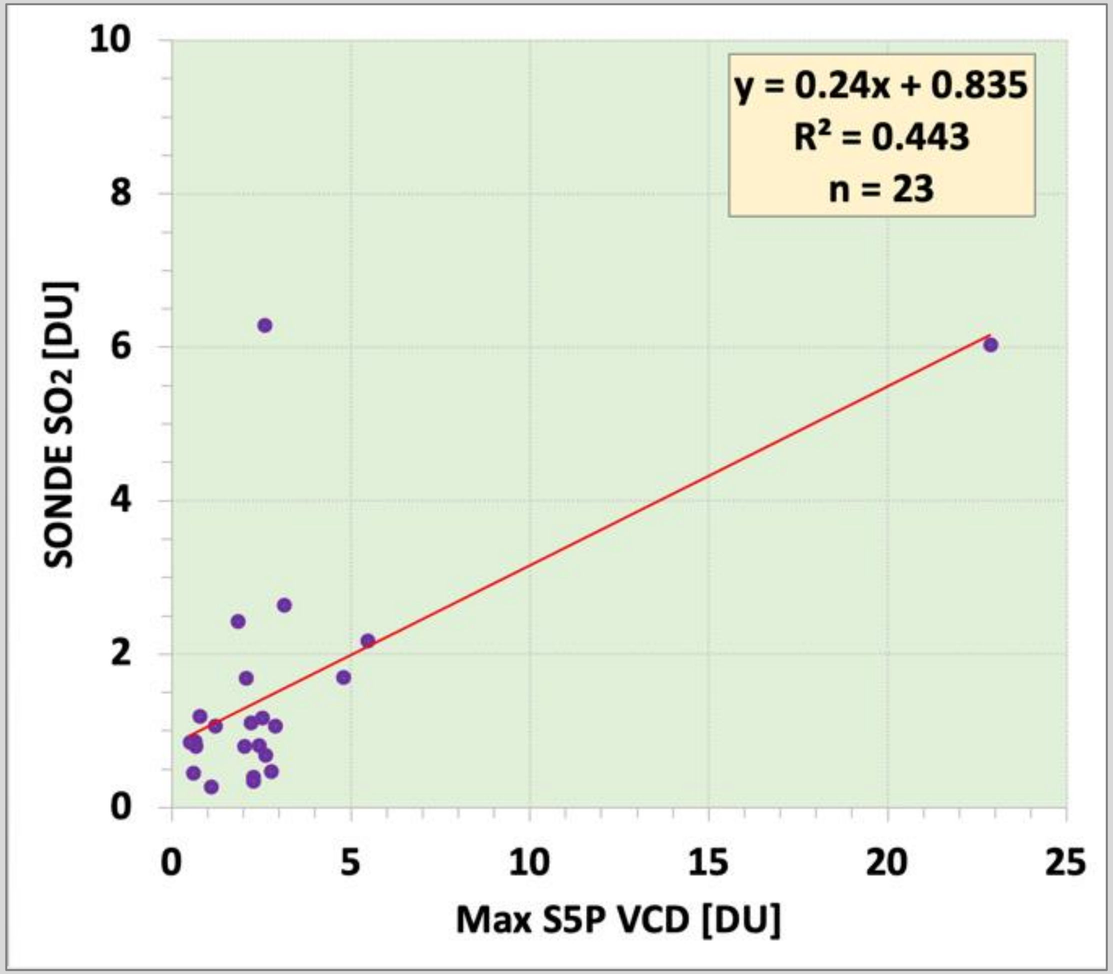
6/1/18 – 3/24/22

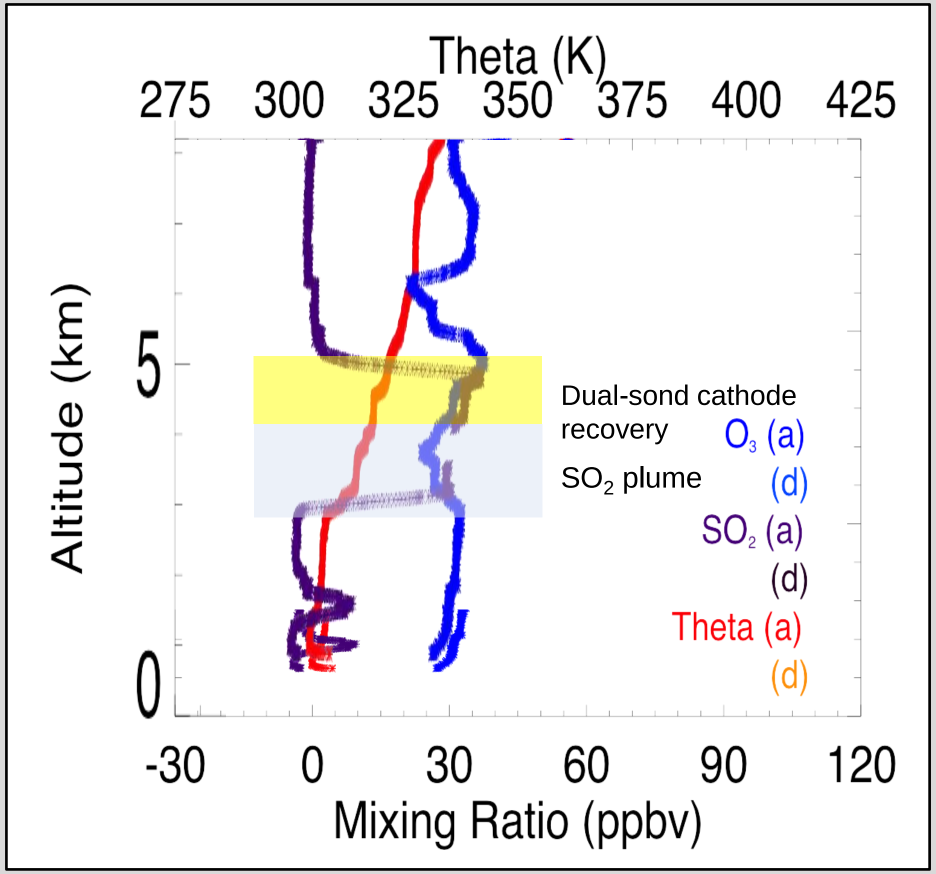




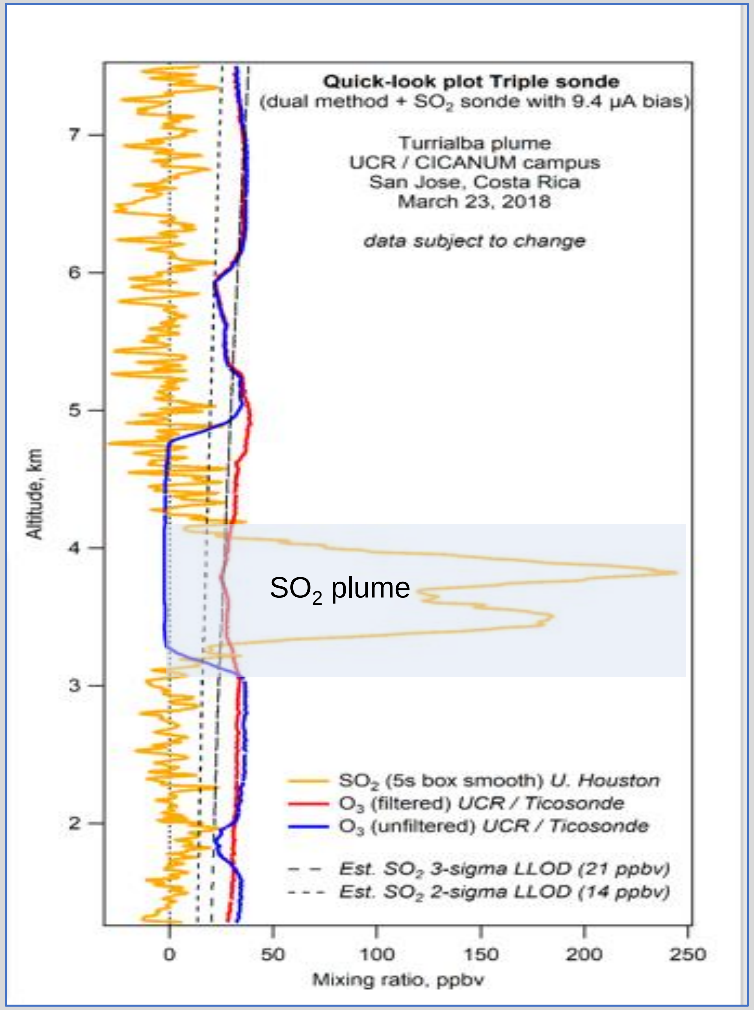
The novel SO_2 sonde

23 March 2018

Dual Sonde (same payload)



SO_2 Sonde*



*Yoon et al., **Development and testing of a novel sulfur dioxide sonde,** https://doi.org/10.5194/amt-15-4373-2022

Summary and conclusions

- Extracted overflight timeseries (50-km radius) for the mean and max SO_2 column centered at Ticosonde sounding sites in the San José, Costa Rica from both OMI PCA TRL and TROPOMI VCD
- Ground-based and balloonsonde as well as OMI and TROPOMI measurements have shown ongoing SO_2 emissions from Turrialba Volcano since at least 2005 to the present
- The Ticosonde balloonsonde measurements downstream of Turrialba provide strong and consistent evidence for SO_2 layers centered close to the 3500-m altitude of Turrialba
- While individual pixels can show close agreement in the column SO_2 between integrated notched profiles, there is no correlation between the OMI station timeseries and the sonde columns
- The higher resolution of the Sentinel 5P overflight timeseries does show correlation, particularly for the maximum pixel within each 50-km sample
- There remain other sample challenges, particularly the ~6-hour time gap between launch and S5P overflight
- Finally, the new SO2 sonde avoids the SO_2 saturation effects that limit the accuracy of the current sounding profiles with single- and dual-ozonesonde approaches

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NASA PSA

NASA's Terra, Aqua and Aura Drifting Orbits Workshop
Novermber 1-2, 2022 (virtual)

https://science.nasa.gov/earth-science/terra-aqua-and-aura-drifting-orbits-workshop-registration

Day 1: 11 am EDT to 6 pm EDT

Session 1

11:00-11:15: *Lucia Tsaoussi* (NASA HQ): NASA HQ perspective, background, goals of Workshop

11:15-11:30: *Steve Platnick* (GSFC, EOS Senior PS): EOSPSO perspective, Workshop structure, how RFI responses were used, Workshop Report.

11:30-11:50: *Bryan Duncan* (GSFC, Aura PS): Review of mission status and future if extended, major themes of Aura RFI responses.

11:50-12:10: *Claire Parkinson* (GSFC, Aqua PS): Review of mission status and future if extended, major themes of Aqua RFI responses.

12:10-12:30: *Kurt Thome*, (GSFC, Terra PS): Review of mission status and future if extended, major themes of Terra RFI responses.

12:30-1:00: Questions/Discussion.

1:00-1:30: Break, East Coast lunch.

Session 2

1:30-3:30: *MODIS Breakout 1* (Ocean/Land), Miguel Román (Leidos, MODIS Science Team Leader), Chairperson; Discipline Leads.

1:30-3:30: *MLS Breakout*, Nathaniel Livesey (JPL, MLS Principal Investigator), Chairperson

1:30-3:30: *CERES Breakout*, Norman Loeb (LARC, CERES Principal Investigator), Chairperson.

3:30-4:00: Break, West Coast lunch

Session 3

4:00-6:00: *MODIS Breakout 2* (Land/Atmosphere), Miguel Román (Leidos, MODIS Science Team Leader), Chairperson; Discipline Leads.

4:00-6:00: *ASTER Breakout*, Michael Abrams (JPL, US ASTER Science Team Leader), Chairperson.

Day 2: 11 am EDT to 6 pm EDT

Session 1

11:00-1:00: *AIRS/AMSU/HSB breakout*, Joao Teixeira (JPL, AIRS/AMSU/HSB Science Team Leader), Chairperson.

11:00-1:00: *OMI breakout*, Joanna Joiner (GSFC, US OMI Science Team Leader), Chairperson.

1:00-1:30: Break, East Coast lunch.

Session 2

1:30-3:30: *MISR breakout*, David Diner (JPL, MISR Principal Investigator), Chairperson.

1:30-3:30: *MOPITT breakout*, Helen Worden (NCAR, US MOPITT Principal Investigator), Chairperson.

3:30-4:00: Break, West Coast lunch.

Session 3

4:00-6:00: *Summary of workshop findings and deliberations*, by Breakout Chairpersons. Discussion. Concluding remarks and what is next, Steve Platnick and Lucia Tsaoussi.

Agenda of Breakout Sessions

TBD